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Spatio-temporal variation in wave power and implications for electricity supply

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ABSTRACT

Wave energy resources are intermittent and variable over both spatial and temporal scales. This is of concern when considering the supply of power to the electricity grid. This paper investigates whether deploying arrays of devices across multiple spatially separated sites can reduce intermittency of supply and step changes in generated power, thereby smoothing the contribution of wave energy to power supply. The primary focus is on the southwest UK; SWAN wave model hindcast data are analysed to assess the correlation of the resource across multiple sites and the variability of power levels with wave directionality. Power matrices are used to calculate step changes in the generated power with increasing numbers of sites. This is extended to national and European scales using ECMWF hindcast data to analyse the impacts of generating power at multiple sites over wider areas. Results show that at all scales the step change in generated power and the percentage of time with zero generation decreases with increasing numbers of sites before plateauing. This has positive implications for performance of electricity grids with high levels of renewable penetration.

1. Introduction

Concerns are often raised over intermittency of electricity generation from renewable sources and associated cost implications as the market share of renewable energy increases [2,13,22]. Depending on the penetration level of renewable generation, intermittency can create problems for grid management [19,35]. Traditionally, electricity demand is predicted and a matching supply is arranged in a pre-set manner. With more intermittent supplies, high levels of flexible balancing plants are required and availability of balancing plants limits the amount of intermittent power that can be integrated into the grid. For example, in Ireland it is estimated that in the period up to 2020 the balancing services will substantially contribute to limiting the proportion of electricity generated from intermittent renewables at any moment to 75% [41].

Marine energy, in the form of wave and tidal stream, is a relative newcomer to the field of renewable electricity generation. Tidal and wave resources differ significantly in their temporal variability. Tidal energy is highly predictable, with spatially phased cyclical intermittency driven by the relative motions of the Earth, Moon and Sun. Studies have investigated the potential reduced intermittency in generated power due to out of phase energy extraction sites around the Northwest European shelf [34,38]. For the first generation (high energy) tidal sites, many key locations are in phase, meaning that peaks in production are amplified and troughs remain [38]. However, as technology develops and allows exploitation of lower energy sites, phase differences between second generation lower flow sites may be more beneficial [39].

Wave energy is less predictable than tidal energy, although more predictable than wind or solar [45]. Wave energy supply is irregular and varies on timescales from individual waves through to long-term variation in storm frequency [30,32]. Resource estimations for wave energy to date have focused on the spatial variability of parameters to define sites [1,5,25,27,52] or considerations of temporal variation to refine forecasts of extractable power [43,55].

Here we consider intermittency of energy supply on timescales from hours to days. High frequency changes in power quality (e.g. Refs. [4,29]), while important, are outside the scope of this contribution. A range of resource assessments have investigated the reduction in intermittency achieved with co-located wind and

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wave farms (e.g Refs. [6,42]), but few resource assessments have focused solely on wave energy intermittency at these spatio-temporal scales. In contrast, a large body of work has investigated characteristics of wind energy intermittency when multiple sites are considered (e.g. Refs. [3,23,26,28]). These studies illustrate how combining power generation from multiple sites leads to reduced intermittency and that the reduction in intermittency depends on the correlation of the resource between sites, with combinations of less well correlated sites providing greater reductions.

An important parameter for electricity supply is the step change in generated power, i.e. the output power change over a certain time interval [28]. Time intervals considered in the literature include 10 min, half hourly, hourly and daily. Step change is also important for electricity markets; for the United Kingdom market the half hour ahead model is particularly important whereas for the North American electricity markets 5 min, half hourly and hourly markets are all used. Smaller step change (lesser variation) is preferable for energy supply since it indicates smoother supply. Uncontrolled step changes are higher for renewable sources such as wind or wave compared to conventional generation. Maximum step change over a specified time series is a useful metric which can be used to compare sites. It has been shown that the value of maximum step change in supply can be reduced based on inter-connecting multiple sites for wind energy [28].

This contribution seeks to assess the premise that, as has been shown for wind, intermittency in wave energy supply may be reduced when multiple spatially separated sites are considered. Complex coastal bathymetry, tidal effects [18,24] and varying storm tracks mean that sites in the same region with similar resource levels may exhibit differences in wave energy in the time domain due to differing exposure to varying wave direction or lags between storm peaks at different locations. Therefore, spatially separated sites may aid in reducing the intermittency of wave energy output to the national grid. Robertson et al. [46] identify times where there is a 100% variation in power output from two wave farms sites in close proximity due to variation in swell exposure. From the grid integration perspective, a consideration of the wave energy at spatially separated sites can provide a better understanding of the amount of wave energy that can be connected to the grid without requirement for additional balancing options.

The work described here considers the impact of combinations of wave energy deployment sites at three spatial scales (Fig. 1): regional, national and continental. A detailed assessment is performed for the Southwest United Kingdom, using ten years of SWAN model [9] hindcast data. The spatial variability of the available resource across the region is described, followed by an investigation into the impacts of power generation at different combinations of sites. Subsequently, the consequences of combinations of site at national (Republic of Ireland and Great Britain) and European scales is presented. Hindcast data from the ECMWF ERA-interim dataset [15] are used. While wave energy contributions to renewable energy over a European scale is somewhat academic in terms of actual grid supply, it is still beneficial to consider European-scale deployment given the combined commitment to combat climate change and reduce carbon emissions.

This study is important to the development of the industry because it demonstrates that the contribution of wave energy to future electricity supply may be poorly represented if considerations of intermittency are based on knowledge of intermittency at one site. Consideration of input of renewable sources such as wave must be considered with multiple sites in the time domain on both a regional (for the distribution network) and national (for the transmission network) basis to give a true reflection of their potential future contribution to grid supply.

2. Study regions

The Northwest European shelf (Fig. 1) is the focus of this study, with four case studies: a regional scale example of the Southwest United Kingdom (SW UK); two national level cases for the Republic

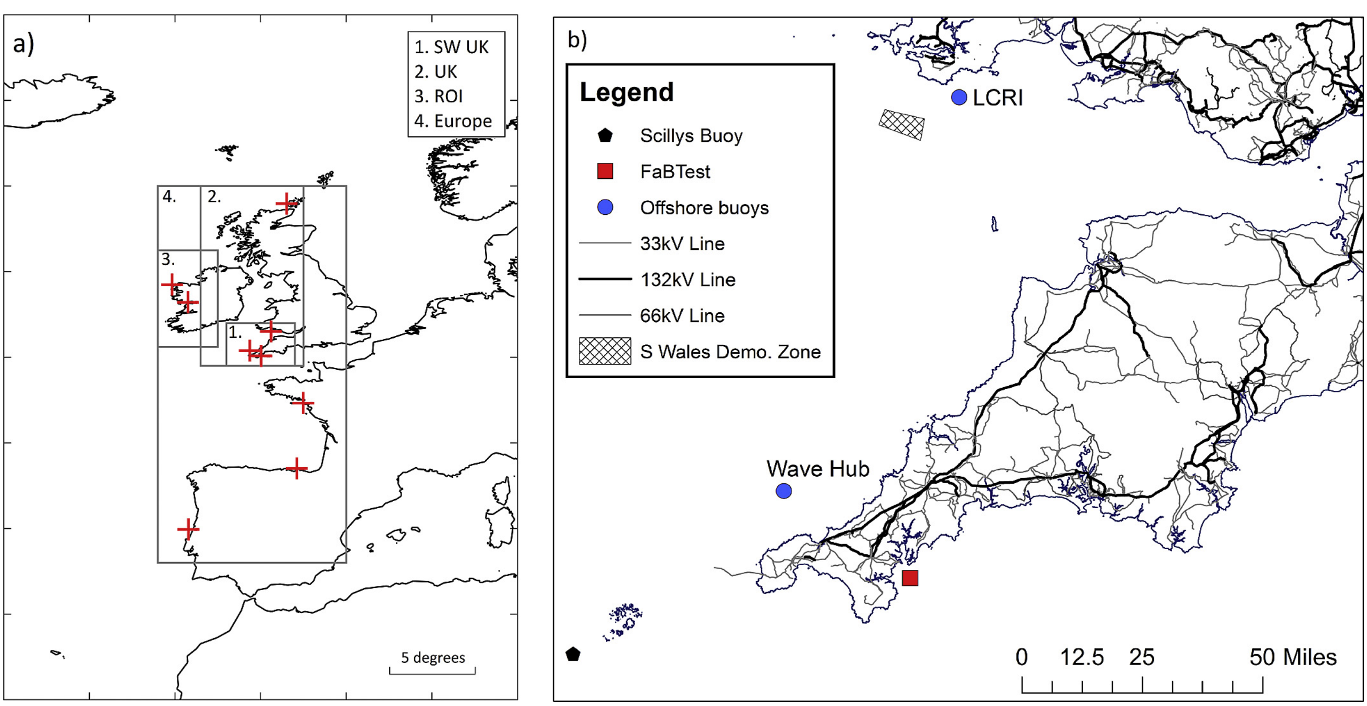

Fig. 1. Maps of a) Western Europe with the 4 study regions highlighted and existing wave energy test facilities marked as red crosses; b) the South West UK showing the location of the different wave buoys used, the South Wales demonstration zone and existing power lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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